

DECLARATION AND POWER OF ATTORNEY



As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name,

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD FOR MAKING THIN FILM SEMICONDUCTOR SOLAR CELL, AND LIGHT EMITTING DIODE (AS AMENDED)

Case No. P97,0027, the specification of which
is attached hereto.

(check
one)

X

was filed on March 14, 1997, as
Application Serial No. 08/818,239
and was amended on _____
(if applicable)

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which application is a continuation-in-part of our application, U.S. Serial No. 08/595,832, which was filed on February 1, 1996.

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims as amended by any amendment referred to above.

I acknowledge the duty to disclose to the United States Patent Office all information, including information which became available between the filing date of Application Serial No. 08/595,832 and the filing date granted this continuation-in-part application, which is known to me to be material to patentability as defined in 37, Code of Federal Regulations, §1.56.¹

I do not know and do not believe this invention was ever known or used in the United States of America before my or our invention thereof, or patented or described in any printed publication in any country before my or our invention thereof or more than one year prior to this application, that the same was not in public use or on sale in the United States of America more than one year prior to this application, and I believe that the invention has not been patented or made the subject of an inventor's certificate issued before the date of this application in any country foreign to the United States of America on an application filed by me or my legal representatives or assigns more than twelve months prior to this application, and that no application for patent or inventor's certificate on this invention has been filed in any country foreign to the United States of America prior to this application by me or my legal representatives or assigns, except as identified below:

I hereby claim foreign priority benefits under Title 35, United States Code, 119 of any foreign application(s) for patent or inventor's certificate listed below

Prior Foreign Application(s)

Number	Country
P07-037655	Japan
P08-061552	Japan
P08-234480	Japan

Date

February 2, 1995

March 18, 1996

September 4, 1996

¹ (b) Under this section, information is material to patentability when it is not cumulative to information already of record or being made of record in the application, and

(1) It establishes, by itself or in combination with other information, a *prima facie* case of unpatentability of a claim; or

(2) It refutes, or is inconsistent with, a position the applicant takes in:

(i) Opposing an argument of unpatentability relied on by the Office, or

(ii) Asserting an argument of patentability.

A *prima facie* case of unpatentability is established when the information compels a conclusion that a claim is unpatentable under the preponderance of evidence, burden-of-proof standard, giving each term in the claim its broadest reasonable construction consistent with the specification, and before any consideration is given to evidence which may be submitted in an attempt to establish a contrary conclusion of patentability.

and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the above listed application on which priority is claimed:

Prior Foreign Application(s)

Number Country Date

If no priority is claimed, I have identified all foreign patent applications filed prior to this application:

Prior Foreign Application(s)

Number Country Date

The power of attorney was changed during the prosecution of this application and I hereby appoint Messrs. John D. Simpson (Registration No. 19,842), Dennis A. Gross (24,410), Robert M. Barrett, (30,142) Steven H. Noll (28,982), Kevin W. Guynn (29,927), Robert M. Ward (26,517), Brett A. Valiquet (27,841), Edward A. Lehman (22,312), David R. Metzger (32,919), Todd S. Parkhurst (26,494), James D. Hobart (24,149), Melvin A. Robinson (31,870), Joseph P. Reagan (35,332), Michael R. Hull (35,902), Michael S. Leonard (37,557), William E. Vaughan (39,056), and Lewis T. Steadman (17,074) all members of the firm of Hill & Simpson, A Professional Corporation

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as my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and direct that all correspondence be forwarded to:

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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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[Title of Document] Specification

[Title of the Invention] Method for separating a device
-forming layer from a base
body

5 [Scope of Claims for a Patent]

[Claim 1]

A method for separating a device-forming
layer from a base body, comprising:

10 making the device-forming layer on the base
body via a separation layer; and

separating the device-forming layer from the
base body by causing mechanical rupture at least at one
of inner portions of the separation layer and
15 interfaces of the separation layer with the device-
forming layer and the base body.

[Claim 2]

The method for separating a device-forming
layer from a base body according to claim 1, wherein
the mechanical strength of said separation layer is
20 weaker than the mechanical strength of said base body
and said device-forming layer.

[Claim 3]

The method for separating a device-forming
layer from a base body according to claim 1, wherein
25 said separation layer is porous.

[Claim 4]

The method for separating a device-forming

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layer from a base body according to claim 1, wherein said separation layer is polycrystalline.

[Claim 5]

5 The method for separating a device-forming layer from a base body according to claim 1, wherein said separation layer is amorphous.

[Claim 6]

10 The method for separating a device-forming layer from a base body according to claim 1, wherein said separation layer is a semiconductor.

[Claim 7]

The method for separating a device-forming layer from a base body according to claim 1, wherein said separation layer is silicon.

15 [Claim 8]

The method for separating a device-forming layer from a base body according to claim 1, wherein said base body is single-crystal.

[Claim 9]

20 The method for separating a device-forming layer from a base body according to claim 1, wherein said base body is polycrystalline.

[Claim 10]

25 The method for separating a device-forming layer from a base body according to claim 1, wherein said base body is single-crystal silicon.

[Claim 11]

The method for separating a device-forming layer from a base body according to claim 1, wherein said base body is cast polycrystalline silicon.

5 [Claim 12]

The method for separating a device-forming layer from a base body according to claim 1, wherein said device-forming layer is a semiconductor.

[Claim 13]

10 The method for separating a device-forming layer from a base body according to claim 1, wherein said device-forming layer is single-crystal silicon.

[Claim 14]

15 The method for separating a device-forming layer from a base body according to claim 1, wherein said mechanical rupture is caused at least at one of inner portions of said separation layer and interfaces of said separation layer with said device-forming layer and said base body by pulling said base body and said
20 device-forming layer in opposite directions.

[Claim 15]

The method for separating a device-forming layer from a base body according to claim 1, wherein said mechanical rupture is caused at least at one of
25 inner portions of said separation layer and interfaces of said separation layer with said base body and said device-forming layer by bonding one of major surfaces

global warming, the time for energy recovery should be reduced to one year or less. Therefore, in order to minimize the energy required for fabricating solar cells, thin-film solar cells are more preferable to thick-film solar cells which need more energy for fabrication.

[0003]

On the other hand, thin-film solar cells can be bent to an extent, which permits them to be mounted along a curved portion of a vehicle body or a curved outer portion of a portable electric appliance, for example, to generate electrical energy. If thin-film solar cells are used in solar battery chargers, they can be compactly folded and can be extended only in actual operation.

[0004]

Conventionally known as thin-film solar cells are amorphous silicon solar cells which are made on plastic substrates. These amorphous silicon solar cells, however, involve the problem that the efficiency is originally low and becomes still lower during its use. To cope with the problem, there has been a demand for thin-film solar cells using single-crystal silicon or polycrystalline silicon having a higher efficiency than amorphous silicon.

[0005]

[Subject that the Invention is to solve]

of said base body remoter from said separation layer to
a first tool, bonding one of major surfaces of said
device-forming layer remoter from said separation layer
to a second tool, and pulling said first and second
tools in opposite directions.

[Claim 16]

The method for separating a device-forming
layer from a base body according to claim 1, wherein
said base body is single-crystal silicon, said
separation layer being porous silicon made by anodic
oxidization of said base body, and said device-forming
layer being single-crystal silicon grown on said
separation layer.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention belongs]

This invention relates to a method for
separating a device-forming layer from a base body
suitable for use in fabricating thin-film solar cells,
for example.

[0002]

[Prior Art]

Forty years or so have passed since the first
solar cell was invented. Although some solar cells are
used in practice, reduction in cost is of a particular
importance for their full-scale use in the future.
Additionally, from the viewpoint of preventing the

Since the temperature becomes significantly high in the process of producing single-crystal silicon or polycrystalline silicon, it is difficult to make such silicon on a plastic or glass substrate.

5 [0006]

The invention has been made to solve the problem involved in the prior art.

[0007]

10 That is, an object of the invention is to provide a method for separating a device-forming layer from a base body, which can fabricate a high-performance thin-film device, such as thin-film solar cell, having a high efficiency.

[0008]

15 [Means for Solving the Problem]

According to the invention, there is provided a method for separating a device-forming layer from a base body, comprising: making the device-forming layer on the base body via a separation layer; and separating
20 the device-forming layer from the base body by mechanically inducing a rupture at least at one of inner portions of the separation layer and interfaces of the separation layer with the device-forming layer and the base body.

25 [0009]

In a typical aspect of the invention, the mechanical strength of the separation layer is lower

than those of the base body and the device-forming layer.

[0010]

The separation layer used in the invention
5 may be porous, polycrystalline or amorphous.

[0011]

In a typical aspect of the invention, the separation layer is made of a semiconductor. The semiconductor may be an element semiconductor or a
10 compound semiconductor. The former may be silicon (Si), and the latter may be gallium arsenide (GaAs).

[0012]

The base body used in the invention is preferably made of a single crystal, but may be made of
15 a polycrystal.

[0013]

The base body used in the invention is preferably made of single-crystal silicon, but may be made of cast polycrystalline silicon, for example.

20 [0014]

In a typical aspect of the invention, the device-forming layer is made of a semiconductor. In this case, the device is a semiconductor device.

[0015]

25 In a preferred embodiment of the invention, the device-forming layer is made of single-crystal silicon.

[0016]

In a typical aspect of the invention, the mechanical rupture is induced at least at one of inner portions of the separation layer and interfaces of the separation layer with the device-forming layer and the base body by pulling the base body and the device-forming layer in opposite directions. More practically, one of major surfaces of the base body opposite from the separation layer is bonded to a first tool while one of major surfaces of the device-forming layer opposite from the separation layer is bonded to a second tool, and the first tool and the second tool are pulled in opposite directions to induce a mechanical rupture at least at one of inner portions of the separation layer and interfaces of the separation layer with the device-forming layer and the base body.

[0017]

In a typical embodiment of the invention, the separation layer is made of porous silicon by anodic oxidation of the base body made of single-crystal silicon, and the device-forming layer of single-crystal silicon is made on the separation layer.

[0018]

In a typical aspect of the invention, after the mechanical rupture of the separation layer, the remainder of the separation layer still lying on the base body is removed by polishing and/or etching, and

the remainder of the separation layer still lying on the rear surface of the device-forming layer is also removed by polishing and/or etching. In the case where the separation layer is made by a process, such as anodic oxidation, which invites a decrease in thickness of the base body, the original thickness can be restored by growing the same material as the base body on the base body.

[0019]

The device-forming layer in the present invention may be used for various devices as a layer on which solar cells, for example, are made.

[0020]

[Operation]

According to the invention having the above-summarized constructions, since the device-forming layer is separated from the base body by inducing a mechanical rupture at least at one of inner portions of the separation layer and interfaces of the separation layer with the device-forming layer and the base body, if the device-forming layer is thin, a thin-film device such as thin-film solar cell can be fabricated by using the thin device-forming layer. In this case, since the device-forming layer is thin and the base body can be used repeatedly without the need for polishing or etching the base body itself upon separating the device-forming layer, thin-film devices such as thin-

film solar cells can be fabricated economically. If the device-forming layer is single-crystal or polycrystalline, high-performance thin-film devices, e.g. thin-film solar cells with a high efficiency, can be obtained. Additionally, the thin-film devices, i.e. thin-film solar cells, can be bent to an extent. That is, flexible thin-film solar cells or other flexible thin-film devices can be obtained.

[0021]

[Embodiment of the Invention]

Some embodiments of the invention are described below with reference to the drawings. In all drawings, the same or equivalent elements are labelled common reference numerals.

[0022]

Figs. 1 through 10 are cross sectional views sequentially showing different steps of a method for fabricating a thin-film solar cell according to a first embodiment of the invention.

[0023]

The method for fabricating a thin-film solar cell according to the first embodiment begins with the step of Fig. 1 where a porous Si layer 2 is made by anodic oxidization of a single-crystal Si substrate 1. The method for making the porous Si layer 2 by anodic oxidization is well known (for example, Applied Physics, Vol. 57, No. 11, p.1710 (1988)). For example,

if the current density is 30 mA and the solution used for the anodic oxidization is $\text{HF}:\text{H}_2\text{O}:\text{C}_2\text{H}_5\text{OH} = 1:1:1$, the porous Si layer 2 obtained has a thickness of 5 μm to 50 μm and a porosity of 10% to 50%. From the viewpoint of repeated use of the single-crystal Si substrate 1, the thickness of the porous Si layer 2 is desired to be minimized to 5 μm to 15 μm , e.g. to 10 μm approximately, in order to minimize the decrease in thickness of the single-crystal Si substrate 1 and to increase the possible time of its use. Additionally, the single-crystal Si substrate 1 is preferably of a p-type, taking it into consideration to make the porous Si layer 2 on it by anodic oxidization; however, even if it is of an n-type, the porous Si layer 2 can be made under appropriate conditions.

[0024]

As shown in Fig. 2, next stacked on the porous Si layer 2 are a p'-type Si layer 3, p-type Si layer 4 and n'-type Si layer 5 by sequential epitaxial growth by CVD, for example, at a temperature of 700°C through 1100°C, for example. Subsequently made on the n'-type layer 5 by CVD, for example, is a protective film 6 which may be either a single-layered SiO_2 or SiN film or a multi-layered film comprising such single-layered films. Thus, the p'-type Si film 3, p-type Si film 4 and n'-type Si film 5 form a solar cell layer, and their typical total thickness is in the range of

1 μ m to 50 μ m, for example, 5 μ m. In this case, in order to improve the crystallinity of the p⁺-type Si film 3, p-type Si film 4 and n⁺-type Si film 5 forming the solar cell layer, it is desired to pre-treat the porous Si layer 2 prior to the epitaxial growth of the Si films 3, 4, 5 to prepare a good condition for subsequent epitaxial growth of these films: namely, the porous Si layer 2 be enforced by oxidization for a short time at a temperature of 400°C to 600°C, for example, to make thin oxide films along inner walls of inner pores of the porous Si layer 2 and the porous Si film 2 be H₂-annealed in a vacuum, for example, at a temperature of 950°C to 1000°C, for example, so as to fill superficial pores of the porous Si layer 2. In this manner, single-crystal p⁺-type Si film 3, p-type Si film 4 and n⁺-type Si film 5 can be obtained (for example, Nikkei Microdevice, July 1994, p.76).

[0025]

Next, as shown in Fig. 3, the entirety of the single-crystal Si substrate 1, on which the porous Si layer 2, p⁺-type Si film 3, p-type Si film 4, n⁺-type Si film 5 and protective film 6 are made, is thermally oxidized such that oxide film 7 of SiO₂ having a thickness of 50nm to 500nm, for example, is formed on the entire surface. During the thermal oxidization, the oxidizing speed of the porous Si layer 2 is faster than the oxidizing speed of the single-crystal Si

substrate 1, and the porous Si layer 2 increases in volume. Therefore, the oxide film 7 has portions like a bird's beak at edge portions of the interface between the porous Si layer 2 and the p'-type Si layer 3, and causes all of the p'-type Si layer 3, p-type Si layer 4, n'-type layer 5 and the protective film 6 to rise up at their edges.

[0026]

After that, the oxide film 7 is removed by etching. As a result, as shown in Fig. 4, wedge-shaped gaps 8 are made at edges of the interface between the porous Si layer 2 and the p'-type Si layer 3. The wedge-shaped gaps 8 facilitate rupture of the porous Si layer 2 when pulled in a subsequent step.

[0027]

Next, as shown in Fig. 5, the rear surface of the single-crystal Si substrate 1 is bonded to a tool 10 by an adhesive 9, and another tool 12 is bonded to the front surface of the protective film 6 by an adhesive 11. These tools 10 and 12 are strong enough to resist the pulling force applied in a subsequent step. For example, they may be made of a metal or quartz, for example. Also the adhesives 9 and 11 are strong enough to resist the pulling force applied in a subsequent step, and they may be a quick-setting bond, for example. In addition, a cutout 13 is made into an edge portion of the porous Si layer 2 to facilitate

rupture of the porous Si layer 2 when pulled in a subsequent step. The cutout 13 may be made by an appropriate mechanical method or by irradiation of a laser beam.

5 [0028]

Next, as shown in Fig. 5, the tools 10 and 12 are pulled with a sufficiently large external force P. The external force P is applied to a site offset from the center of the single-crystal Si substrate 1 toward the edge with the cutout 13 of the porous Si layer 2 to invite stress concentration at the edge of the porous Si layer 2. As a result, since the porous Si layer 2 is inherently weak in mechanical strength and because of the existence of the cutout 13 in the edge wall of the porous Si layer 2 and the wedge-shaped gap 8 at the edge of the interface between the porous Si layer 2 and the p'-type Si layer 3, stress concentration occurs prominently in these portions, and, as shown in Fig. 6, rupture occurs in the porous Si layer 2 and/or along the interface between the porous Si layer 2 and the p'-type Si layer 3. In this manner, the single-crystal Si substrate 1 and the block of the p'-type Si layer 3, p-type Si layer 4, n'-type Si layer 5 and protective film 6 are separated from each other.

25 [0029]

Next, as shown in Fig. 7, part of the porous Si layer 2 still remaining on the surface of the

single-crystal Si substrate 1 and on the surface of the p⁺-type Si layer 3, respectively, even after the rupture is removed by etching using an etchant such as HF/H₂O₂, for example. The single-crystal Si substrate 1 is used again as the substrate for fabricating another thin-film solar cell after removing the adhesive 9, detaching the tool 10, and polishing the surface. If the thickness of the porous Si layer 2 is 10μm, the thickness of the single-crystal Si substrate 1 lost by the polishing for the next use is 3μm or so, then the thickness of the single-crystal Si substrate 1 reduced in one cycle of fabrication of a thin-film solar cell is 13μm. Therefore, the single-crystal Si substrate 1 loses a small amount of its thickness only by 130μm even after used ten times, which means that each single-crystal Si substrate 1 can be used at least ten times.

[0030]

Next, as shown in Fig. 8, the exposed surface of the p⁺-type Si layer 3 is bonded to a surface of a glass substrate 14, for example, by an adhesive 15. The adhesive 15 may be an epoxy resin, for example.

[0031]

After removing the adhesive 11 and detaching the tool 12 from the protective film 6, the protective film 6 is selective etched off to make an opening 6a as shown in Fig. 9. Made through the opening 6a is an

electrode 16 on incident surface (also called a front electrode) on the n⁺-type Si layer 5. The front electrode 16 may be made by printing, for example. Apart from it, a plastic substrate 18 is prepared, having on it a metal layer 17 positionally corresponding to and geometrically identical to the front electrode 16, the front electrode 16 and the metal layer 17 are connected together. A gap made upon the connection between the protective film 6 and the plastic substrate 18 is filled with a transparent adhesive 19 of an epoxy resin, for example, to bond the protective film 6 and the plastic substrate 18 entirely.

[0032]

After that, the glass substrate 14 is detached from the p⁺-type Si substrate 3 by removing the adhesive 15. Then, as shown in Fig. 10, a rear electrode 20 is formed on the p⁺-type Si layer 3 by printing, for example, and a plastic substrate 22 is bonded to the rear electrode 20 with an adhesive 21. The rear electrode 20 serves also as a reflective plate for reflecting incident light in the thin-film solar cell, and contributes to an increase in efficiency.

[0033]

In the process shown above, the intended thin-film solar cell is completed, in which the p⁺-type Si layer 3, p-type Si layer 4, n⁺-type Si layer 5 and

protective film 6, which make up a solar cell, are sandwiched between two plastic substrates 18 and 22.

[0034]

As explained above, according to the first embodiment of the invention, a thin-film solar cell is made by epitaxially growing the single-crystal p'-type Si layer 3, p-type Si layer 4 and n'-type Si layer 5 forming the solar cell layer in this order on the single-crystal Si substrate 1 via the porous Si layer 2, then separating the solar cell layer from the single-crystal Si substrate 1 by mechanically rupturing the porous Si layer 2 with a pulling force, and then sandwiching the solar cell layer between two plastic substrates 18 and 22. In this case, because of the solar cell layer being single-crystal, the thin-film solar cell exhibits a high efficiency and a satisfactory reliability. In addition, because of the single-crystal Si substrate 1 being usable repeatedly, the use of a mechanical method for separating the solar cell layer from the single-crystal Si substrate 1, the use of inexpensive plastic substrates 18 and 22, and other reasons, the thin-film solar cell can be fabricated at a low cost. Further, because the solar cell layer is thin and can be bent to an extent and because the plastic substrates 18 and 22 are flexible, the entirety of the thin-film solar cell can be bent to a certain extent and can be widely used such as being

mounted along a curved portion of a car body or an outer curved portion of a portable electric appliance, for example.

[0035]

5 That is, according to the first embodiment, thin-film solar cells having a high efficiency, high reliability and flexibility can be fabricated economically.

[0036]

10 Next explained is a second embodiment of the invention.

[0037]

15 The method for fabricating a thin-film solar cell according to the first embodiment applies the external force P to the tools 10 and 12 in the manner shown in Fig. 5 upon separating the p⁺-type Si layer 3, p-type Si layer 4, n⁺-type Si layer 5 and protective film 6 from the single-crystal Si substrate 1 by rupturing the porous Si layer 2. In contrast, the
20 method for fabricating a thin-film solar cell according to the second embodiment ruptures the porous Si layer 2 by applying the external force P to the tools 10 and 12 in a different manner as shown in Fig. 11 to separate the p⁺-type Si layer 3, p-type Si layer 4, n⁺-type Si
25 layer 5 and protective film 6 from the single-crystal Si substrate 1. The other features of the method according to the second embodiment are identical to the

method according to the first embodiment, and their explanation is not repeated here.

[0038]

Also the second embodiment, like the first
5 embodiment, can fabricate inexpensive thin-film solar cells having a high efficiency, high reliability and flexibility.

[0039]

Next explained is a third embodiment of the
10 invention.

[0040]

As shown in Fig. 10, in the method for fabricating a thin-film solar cell according to the first embodiment where the entire surface of the p⁺-type Si film 3 is in contact with the rear electrode
15 20, recombination of electron-hole pairs generated by incident light is liable to occur along the interface between the p⁺-type Si layer 3 and the rear electrode 20 and is likely to decrease the efficiency. Taking it
20 into consideration, the method according to the third embodiment makes a protective film 23 in the form of a single-layered SiO₂ film, SiN film or a multi-layered film comprising these single-layered films on the p⁺-type Si layer 3 as shown in Fig. 12, then makes an
25 opening 23a in the protective film 23, makes a rear electrode 24 through the opening 23a by printing, and connects the rear electrode 24 to a metal layer 25

preliminarily formed on the plastic substrate 22. A gap made upon the connection between the protective film 23 and the metal layer 25 is filled with a transparent adhesive 26 of an epoxy resin, for example, to bond the protective film 23 and the metal layer 25 entirely. The other features of the method according to the third embodiment are identical to the method according to the first embodiment, and their explanation is not repeated here.

[0041]

Since the third embodiment significantly decreases recombination of electron-hole pairs along the interface between the p⁺-type Si layer 3 and the rear electrode 24, it can provide a thin-film solar cell with a higher efficiency than that made by the first embodiment while having the same advantages as those of the first embodiment.

[0042]

Next explained is a fourth embodiment of the invention.

[0043]

The method for fabricating a thin-film solar cell according to the first embodiment once bonds the rear surface of the solar cell layer to the glass substrate 14 in the step shown in Fig. 8 and, after detaching the glass substrate 14, bonds the solar cell layer to the plastic substrate 22 in the step shown in

Fig. 10. The method according to the fourth embodiment, however, straightforwardly makes the rear electrode 20 by printing on the p-type Si layer 3 without bonding the solar cell layer to the glass substrate 14, and then bonds the rear electrode 20 to the plastic substrate 22 with the adhesive 21. After that, the method detaches the tool 12 by removal of the adhesive 11, then makes the opening 6a in the protective film 6 and the front electrode 16 in the opening 6a, connects the front electrode 16 with the metal layer 17 on the plastic substrate 18, and bonds the protective film 6 to the plastic substrate 18 by filling the gap between them with the adhesive 19. The other features of the method according to the fourth embodiment are identical to the method according to the first embodiment, and their explanation is not repeated here.

[0044]

According to the fourth embodiment, the manufacturing process can be simplified as compared with the first embodiment, and more economical thin-film solar cells can be fabricated.

[0045]

Next explained is a fifth embodiment of the invention.

[0046]

Although the method for fabricating a thin-

film solar cell according to the first embodiment makes the front electrode 16 in the step shown in Fig. 9, the method according to the fifth embodiment makes the front electrode 16 together with the opening 6a in the protective film 6 in the step shown in Fig. 3. The other features of the method according to the fifth embodiment are identical to the method according to the first embodiment, and their explanation is not repeated here.

[0047]

Also the fifth embodiment gives the same advantages as those of the first embodiment.

[0048]

Next explained is a sixth embodiment of the invention.

[0049]

In the method for fabricating a thin-film solar cell according to the sixth embodiment, the solar cell layer has a double-hetero structure. That is, as shown in Fig. 13, the sixth embodiment epitaxially grows a p⁺-type Si layer 31, p-type Si_{1-x}Ge_x graded layer 32, undoped Si_{1-y}Ge_y layer 33, for example, n-type Si_{1-x}Ge_x graded layer 34 and n⁻-type Si layer 35 on the porous Si layer 2 in this order to make a solar cell layer of a double-hetero structure. In this case, the composition ratio x of Ge in the p-type Si_{1-x}Ge_x graded layer 32 monotonously increases in the thickness

direction of the p-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 32 from the value of 0 at the interface between the p'-type Si layer 31 and the p-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 32 to the value of y at the interface between the $\text{Si}_{1-y}\text{Ge}_y$ graded layer 33 and the p-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 32. The composition ratio x of Ge in the n-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 34 monotonously increases in the thickness direction of the n-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 34 from the value of 0 at the interface between the n'-type Si layer 35 and the n-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 34 to the value of y at the interface between the $\text{Si}_{1-y}\text{Ge}_y$ graded layer 33 and the n-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 34. In this manner, lattices match at respective interfaces of p'-type Si layer 31, p-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 32, $\text{Si}_{1-y}\text{Ge}_y$ layer 33, n-type $\text{Si}_{1-x}\text{Ge}_x$ graded layer 34 and n'-type Si layer 35, and an excellent crystallinity can be obtained. The other features of the method according to the sixth embodiment are identical to the method according to the first embodiment, and their explanation is not repeated here.

[0050]

According to the sixth embodiment, because of the solar cell layer having a double-hetero structure and capable of effectively confining carriers and light in its central $\text{Si}_{1-y}\text{Ge}_y$ layer 33, a high efficiency can be obtained, and the same various advantages as those of the first embodiment can be obtained.

[0051]

Next explained is a seventh embodiment of the invention, which is an application of the invention to a method for fabricating a CMOS semiconductor device.

5 [0052]

The method for fabricating a CMOS semiconductor device according to the seventh embodiment first makes the porous Si layer 2 on the single-crystal Si substrate 1 as shown in Fig. 14, and then epitaxially grows a single-crystal p-type Si layer 10 41 on the porous Si layer 2 by CVD, for example. The thickness of the p-type Si layer 41 is chosen appropriately, for example, to 5 μ m. The impurity concentration of the p-type Si layer 41 may be, for 15 example, about 10^{15}cm^{-3} .

[0053]

Next, as shown in Fig. 15, an n-well 42 is formed by selectively doping an n-type impurity in the p-type Si layer 41 by ion implantation or thermal 20 diffusion. After that, a gate insulating film 43, such as SiO₂ film, is made on the p-type Si layer 41 by thermal oxidization, for example, on which gate electrodes 44, 45 are next made on the gate insulating layer 43. These gate electrodes 44, 45 may be made, 25 for example, by forming a polycrystalline Si film on the gate insulating film 43 by CVD or other appropriate method, then lowering the resistance by doping an

impurity in the polycrystalline Si film, and patterning the impurity-doped polycrystalline Si film by etching.

[0054]

After that, by ion-implanting an n-type impurity in the p-type Si film 41, using the gate electrode 44 as a mask, while covering the surface of the portion of the n-well 42 with a mask, n'-type regions 46, 47 used as source and drain regions are made in self-alignment with the gate electrode 44.

After removing the mask used for ion implantation of the n-type impurity and in the presence of another mask covering the surface of the remainder portion other than the portion of the n-well 42, a p-type impurity is ion-implanted in the n-well 42, using the gate electrode 45 as a mask, to form p'-type regions 48, 49 used as source and drain regions in self-alignment with the gate electrode 45.

[0055]

After that, an inter-layer insulating film such as SiO_2 film is formed on the entire surface by CVD, for example, and the inter-layer insulating film 50 is selectively etched off to make contact holes 50a, 50b, 50c and 50d. After an Al film, for example, is next made on the entire surface by sputtering or vacuum evaporation, for example, the Al film is patterned by etching to form electrodes 51, 52, 53 and 54. In this case, the gate electrode 44 and n'-type regions 46, 47

make up an n-channel MOS transistor, and the gate electrode 45 and p⁺-type regions 48, 49 make up a p-channel MOS transistor. These n-channel MOS transistor and p-channel MOS transistor make up a CMOS.

5 [0056]

After that, in the same manner as shown in Fig. 5 of the first embodiment, the rear surface of the single-crystal Si substrate 1 is bonded to the tool 10 by the adhesive 9, and the tool 12 is bonded to the surface of the CMOS semiconductor device by the adhesive 11. Next, these tools 10 and 12 are pulled in opposite directions by external forces P to rupture the porous Si layer 2 and to separate the CMOS semiconductor device from the single-crystal Si substrate 1.

15 [0057]

After that, the porous Si layer 2, if any, is removed from the rear surface of the p-type Si layer 41, and the tools 10 and 12 are detached. Then, as shown in Fig. 16, the rear surface of the p-type Si layer 41 is bonded to a heat sink 55 of a metal or other material with silver paste, for example. After that, the structure is pelletized, if desired.

20 [0058]

In this manner, the CMOS semiconductor device having the heat sink 55 on the rear surface of the p-type Si layer 41 is completed.

[0059]

According to the seventh embodiment, since the p-type Si layer 41 forming an active layer is single-crystal, inexpensive CMOS semiconductor devices having a high performance equivalent to that of CMOS using bulk Si can be produced. Additionally, since the CMOS semiconductor device has the heat sink 55 on the rear surface of the p-type Si layer 41, the temperature does not increase so much during operation, and deterioration or malfunction caused by an increase in temperature can be prevented.

[0060]

Next explained is an eighth embodiment of the invention, which is an application of the invention to a method for fabricating a semiconductor laser of a double-hetero structure.

[0061]

The method for fabricating a semiconductor laser according to the eighth embodiment first makes a porous GaAs layer 62 on a single-crystal GaAs substrate 61 as shown in Fig. 17. Next epitaxially grown on the porous GaAs layer 62 is an n-type GaAs layer 63 on which epitaxially grown are an n-type AlGaAs layer 64 as an n-type cladding layer, active layer 65 of GaAs and p-type AlGaAs layer 66 as a p-type cladding layer in sequence to form a laser structure. The thickness of the n-type GaAs layer 63 is chosen appropriately,

for example, to 5 μ m.

[0062]

In the same manner as shown in Fig. 5 of the first embodiment, the rear surface of the single-crystal GaAs substrate 61 is bonded to the tool 10 by the adhesive 9, and the tool 12 is bonded to the front surface of the p-type AlGaAs layer 66 by the adhesive 11. After that, these tools 10 and 12 are pulled in opposite direction by external forces P to rupture the porous GaAs layer 62 and to separate the block of the n-type GaAs layer 63, n-type AlGaAs layer 64, active layer 65 and p-type AlGaAs layer 66 from the single-crystal GaAs substrate 61.

[0063]

After removing the porous GaAs layer 62 remaining on the n-type GaAs layer 63 and detaching the tools 10 and 12, an n-side electrode (not shown) is formed on the rear surface of the n-type GaAs layer 63, and a p-side electrode (not shown) is formed on the p-type AlGaAs layer 66. Thus, an intended semiconductor laser having a double-hetero structure is obtained.

[0064]

According to the eighth embodiment, inexpensive semiconductor lasers having a double-hetero structure can be fabricated. Additionally, since the n-type GaAs layer 63 serving as a substrate of the semiconductor laser is very thin as compared with an n-

type GaAs substrate typically used in conventional semiconductor lasers, the series resistance of the substrate can be reduced remarkably, and the voltage for operating the semiconductor laser can be reduced so much.

[0065]

Having described a specific preferred embodiment of the present invention with reference to the accompanying drawings, it is to be understood that the invention is not limited to that precise embodiment, and that various changes and modifications may be effected therein by one skilled in the art without departing from the scope or the spirit of the invention as defined in the appended claims.

[0066]

For example, although the first embodiment epitaxially grows the p'-type Si layer 3, p-type Si layer 4 and n'-type Si layer 5 on the porous Si layer 2 by CVD, it can be modified such that an amorphous Si layer is formed on the porous Si layer 2 by plasma CVD or other appropriate process and then annealed at a temperature of 600°C to 800°C to crystallize the amorphous Si layer by solid phase growth. In this case, since the porous Si layer 2 behaves as a seed crystal, a high-quality solid epitaxial layer can be obtained.

[0067]

The $\text{Si}_{1-y}\text{Ge}_y$ 33 used in the sixth embodiment may be replaced by a Ge layer.

[0068]

The invention is also applicable to
5 fabrication of SOI (silicon on insulator) substrates, for example.

[0069]

[Effect of the Invention]

As described above, since the invention
10 separates a device-forming layer from a base body by causing mechanical rupture at least at one of inner portions of a separation layer and interfaces of the separation layer with the base body and the device-forming layer, high-performance thin-film devices, such
15 as thin-film solar cells having a high efficiency, can be made economically.

[Brief Description of the Drawings]

[Fig. 1]

Cross-sectional view for explaining a method
20 for fabricating a thin-film solar cell according to a first embodiment of the invention.

[Fig. 2]

Cross-sectional view for explaining the
method for fabricating a thin-film solar cell according
25 to the first embodiment of the invention.

[Fig. 3]

Cross-sectional view for explaining the

method for fabricating a thin-film solar cell according to the first embodiment of the invention.

[Fig. 4]

5 Cross-sectional view for explaining the method for fabricating a thin-film solar cell according to the first embodiment of the invention.

[Fig. 5]

10 Cross-sectional view for explaining the method for fabricating a thin-film solar cell according to the first embodiment of the invention.

[Fig. 6]

 Cross-sectional view for explaining the method for fabricating a thin-film solar cell according to the first embodiment of the invention.

15 [Fig. 7]

 Cross-sectional view for explaining the method for fabricating a thin-film solar cell according to the first embodiment of the invention.

[Fig. 8]

20 Cross-sectional view for explaining the method for fabricating a thin-film solar cell according to the first embodiment of the invention.

[Fig. 9]

25 Cross-sectional view for explaining the method for fabricating a thin-film solar cell according to the first embodiment of the invention.

[Fig. 10]

Cross-sectional view for explaining the method for fabricating a thin-film solar cell according to the first embodiment of the invention.

[Fig. 11]

5 Cross-sectional view for explaining a method for fabricating a thin-film solar cell according to a second embodiment of the invention.

[Fig. 12]

10 Cross-sectional view for explaining a method for fabricating a thin-film solar cell according to a third embodiment of the invention.

[Fig. 13]

15 Cross-sectional view for explaining a method for fabricating a thin-film solar cell according to a sixth embodiment of the invention.

[Fig. 14]

Cross-sectional view for explaining a method for fabricating a CMOS semiconductor device according to a seventh embodiment of the invention.

20 [Fig. 15]

Cross-sectional view for explaining the method for fabricating a CMOS semiconductor device according to the seventh embodiment of the invention;

[Fig. 16]

25 Cross-sectional view for explaining the method for fabricating a CMOS semiconductor device according to the seventh embodiment of the invention.

[Fig. 17]

Cross-sectional view for explaining a method
for fabricating a semiconductor laser according to an
eighth embodiment of the invention.

5 [Description of Reference Numerals]

1 Single-crystal Si substrate

2 Porous Si layer

3 p'-type Si layer

4, 41 p-type Si layer

10 5 n'-type Si layer

6, 23 Protective film

7 Oxide film

9, 11, 15, 19, 21 Adhesive

10, 12 Tools

15 14 Glass substrate

16 Front electrode

18, 22 Plastic substrate

[Title of Document] Abstract

[Abstract]

[Object]

5 The method for separating a device-forming
layer from a base body, which can fabricate a high-
performance thin-film device, such as thin-film solar
cell, having a high efficiency at a low cost is
provided.

[Construction]

10 A porous Si layer 2 is formed on a single-
crystal Si substrate 1, and then a p'-type Si layer 3,
p-type Si layer 4 and n'-type Si layer 5 which all make
up a solar cell layer. After a protective film 6 is
15 made on the n'-type Si layer 5, the rear surface of the
single-crystal Si substrate 1 is bonded to a tool 10,
and another tool 12 is bonded to the front surface of
the protective film 6. Then, the tools 10 and 12 are
pulled in opposite directions to mechanically rupture
20 the porous Si layer 2 and to separate the solar cell
layer from the single-crystal Si substrate 1. The
solar cell layer is subsequently sandwiched between two
plastic substrates to make a flexible thin-film solar
cell.

[Selected Drawing] Fig. 5